Development of methods for managing energy consumption and energy efficiency in a common system

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ABSTRACT

The work aims to analyze and examine renewable energy sources (RES) to develop interconnected energy efficiency and energy consumption management system by integrating the software-defined machine-to-machine (M2M) communication. The article's objectives include analysis of using RES as alternative raw materials for electricity production, the study of intelligent technologies for integrating RES into monitoring and control systems, research of devices and methods for monitoring energy production and consumption, analysis of sensor application for automation of control systems in the energy sector, a study of data transmission and information processing rates. The study results showed that the data transfer rate was delayed by 6 seconds to process 1,000 MB of information. It has been proven that wind energy can be used most efficiently within a 12-hour daily cycle, in contrast to tidal energy and solar energy. It is shown that due to the cyclical nature of obtaining energy from renewable sources, they do not fully provide energy to a large city, on the basis of which it is necessary to additionally use other energy sources. Three different types of power generation facilities were examined and compared. Wind farms were found to have the highest potential for electricity generation, amounting to 1,600-1,700 kW.

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1. INTRODUCTION

Today the energy sector is a crucial element in the functioning and prosperity of economics in many countries worldwide, with new prospects for a gradual transition from existing traditional to alternative energy generation methods, particularly renewable energy sources (RES) [1], [2]. Successful implementation of intelligent energy management (IEM) involves real-time information about the load profile, power supply, and system operating conditions [3], [4]. However, the communication network needed for IEM is very different from conventional human-centric telecommunications networks. This type of communication is characterized by the omnipresent exchange of information between many intelligent machines like sensors, actuators, intelligent electronic devices (IEDs), excluding the human factor. This resulted in the introduction of machine-to-machine (M2M) communication technology [5], [6].

Cellular technology is a major driver of M2M due to the pervasive presence of cellular infrastructure and the availability of high-speed access. The 3rd generation partnership project (3GPP) has defined several methods to support M2M communication in modern long-term evolution-advanced

(LTE-advanced) systems [7]. M2M devices may co-exist with human communications on the same network and use a random-access channel to establish connections to centralized base stations. As a result, M2M communication, with its self-organization, self-adjustment, and self-healing skills, should be a critical factor in the reliable functioning of intelligent energy management.

The application-specific method requires full customization of M2M platforms for a specific application scenario, which does not allow to adapt to a rapidly evolving demand. Managing a large number of M2M devices is highly inefficient due to the increasing complexity of the system and the significant heterogeneity of equipment, interconnections, and deployment scenarios. Second, the close interconnectivity between applications and task-based hardware makes reusing existing M2M physical infrastructure for new applications impossible. Different or even the same application by different operators require redundant equipment, resulting in excessive capital and operating costs. Finally, power grid applications have various quality of service (QoS) requirements regarding latency, packet size, bandwidth, and packet arrival rates. The co-existence of protection, control, monitoring, and billing traffic in a single communication network creates new challenges for effective resource allocation in M2M communications [8]. Network design, deployment, management, and maintenance can be easily implemented on one central controller based on an open standard rather than directly setting up many heterogeneous devices [9].

This study investigates the SDN-M2M switching relationship and explores the potential for intelligent control using RES. This work aims to analyze and examine RES in developing a methodology for energy efficiency and energy consumption management in the overall control system by integrating software-defined M2M technology. The scientific novelty implies a rational application of RES in the energy sector through the conversion of energy by wind turbines, solar panels, and hydropower plants based on software inter-machine communication.

2. METHOD

This study analyzes the use of RES in grid-connected intelligent energy management systems using software-defined M2M communication. The work investigates the operation of wind farms with sensors for power generation and monitoring information with rational power distribution; solar panels with irradiation sensors, solar panel temperature, and surge sensors; hydro power plant (HPP) for power generation with special monitoring systems and power supply to the plant. The RES considered in this study is wind, solar, and water.

2.1. Wind power plant

The wind power plant (WPP) is a complex of related equipment and facilities designed to convert wind flows into energy to produce other types of energy like electricity and mechanical power. The conversion of wind streams into electrical energy is due to the electric generator, which is contained in the plant's construction. A scheme to monitor wind power production is presented in Figure 1.

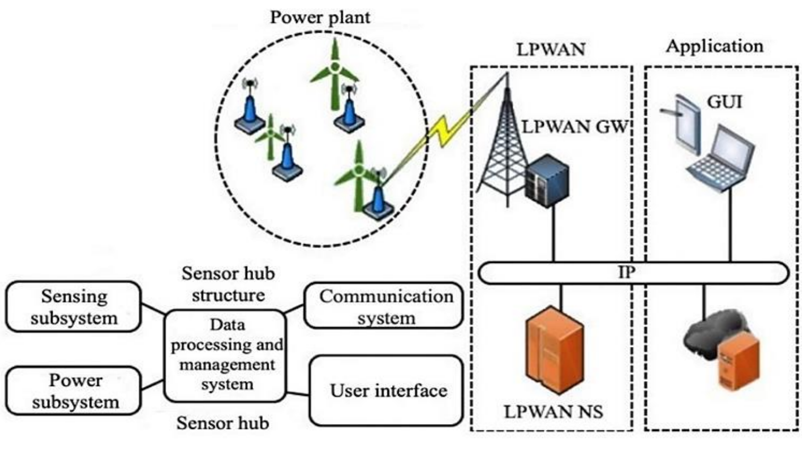

Figure 1. WPP with wind turbines and communication systems

It comprises three major components: sensors, low-power wide-area network (LPWAN) gateway, data pathway, database, and visualization solution. Sensors are installed on or around generators that measure voltage, current, phase, and other necessary parameters for electricity generation. Sensors can also measure and monitor infrastructure parameters such as temperature, vibration, and environmental parameters such as wind speed, humidity, and lighting conditions [10], [11].

2.2. Solar panels and solar energy

A solar panel is a set of photovoltaic converters in the form of semiconductor devices that convert solar energy into direct electric power. Figure 2 shows a system for monitoring electricity generation through solar panels and parameter sensors. A low-cost Arduino voltage sensor module with voltage splitters can be used to measure the output voltage. This module is based on the principle of resistance point pressure, and it can make the input voltage of the red terminal decrease by a factor of 5 from the original voltage [12], [13].

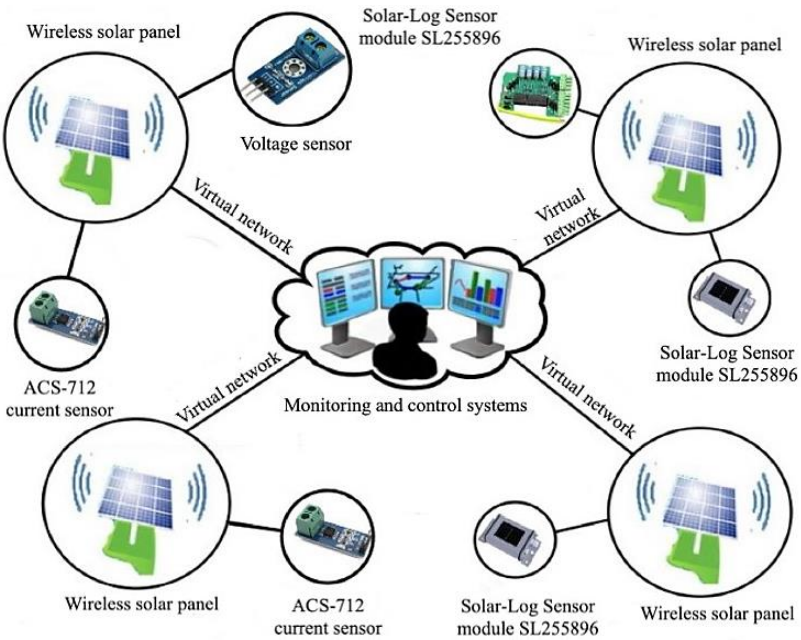

Figure 2. Sensor-based solar panel control system

2.3. Tidal power plant

Tidal energy is a type of hydroelectric production that uses water as a raw material to generate electrical energy converted by tidal motion using tidal generators. There are several ways of producing energy, one of which is through tidal generators or energy converters (TECs). Tidal generators use kinetic energy from tidal water movement to turbines [14]–[16]. Figure 3 shows HPP with tidal power generation. Figure 4 shows the way to supply generated hydroelectric power to a small city through HPP through a special wire transmitter. HPP with tidal hydropower can generate more than 2 MW of electricity.

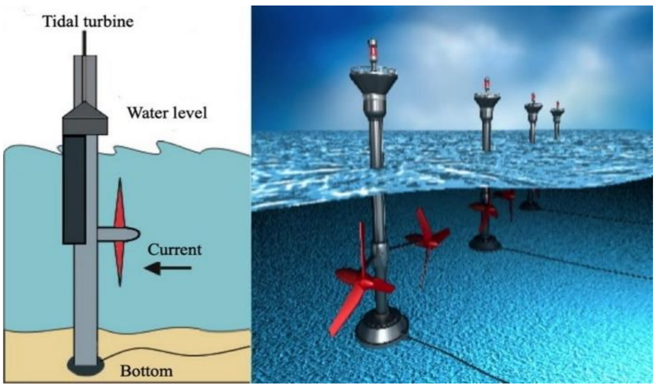

Figure 3. HPP with tidal power generation

Figure 4. Power supply to the city by HPPs

2.4. Intelligent energy management with SDN-M2M technology

IEM combines defined machine learning programs to allocate resources in fine granularity and ensure QoS. Figure 5 shows the SD-M2M architecture comprising such layers as energy sources and control, application, transmission, management, and administration of information. The data layer represents the presence of programmable field equipment and network elements involved in M2M communication (sensors, actuators, smart meters, gateways, switches, routers). They are needed to support autonomous data collection and transmission with IEM.

The application layer includes IEM application networks (domestic energy management, corporate energy management, building energy management, micro-grid energy management, electric vehicle energy management). Using standard application programming interfaces (APIs) between the control layer and the applications, intelligent energy management applications can communicate the requirements to the appropriate controllers through the north-facing interface [17]–[19]. IEM using RES is an interconnected set of equipment, devices, and data carriers to monitor and control energy supply systems and energy consumption.

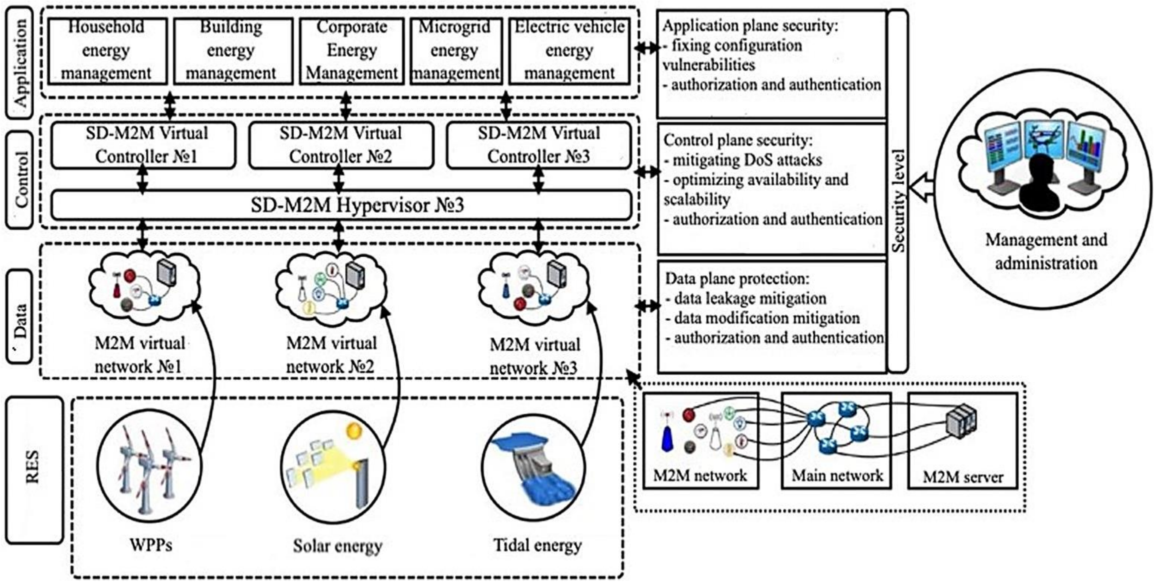

Figure 5. SDN-M2M architecture

Figure 6 shows different RES (hydropower, wind turbines, solar panels) data control sensors to transfer information to DC for further monitoring and control of the equipment. The points in Figure 6 are the nodes of energy distribution. The electrical substation in Figure 6 is designed to receive, convert, and distribute electricity with the help of control devices and switchgear. The conversion sub-station serves to convert the current type and its frequencies.

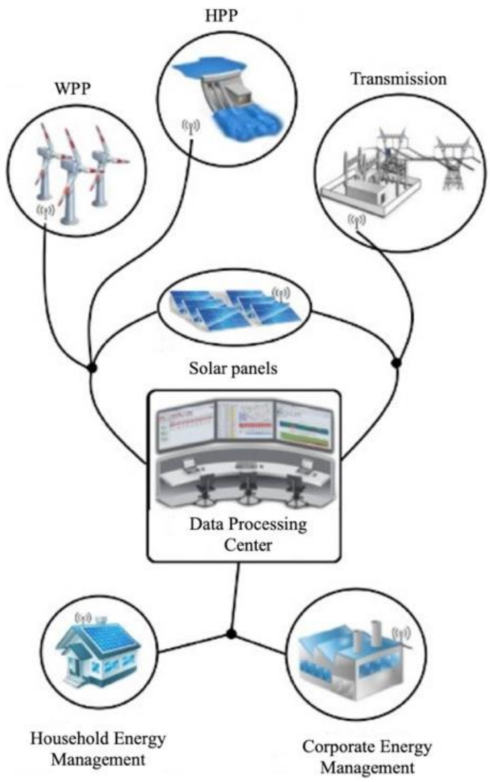

Figure 6. Renewable energy complex with data transmission and processing

3. RESULTS AND DISCUSSION

The results of transmitting the signal from the equipment are given in Figure 7. Thus, the data transmission rate may slow because of the increase in the amount of information over time. The delay in the transmission rate is because multiple calculation processes are executed simultaneously. The transmission of data from wind turbines and HPPs, together with the calculation of the joint flow of solar panels, can lead to a non-significant delay. In addition, natural factors, such as meteorological conditions and sufficiently low temperatures below 20-25 ℃. The data center information technology determines the node where the power generated by the plants is measured. It enables the distribution of electricity consumption based on the energy produced by the power plants.

The rate of data processing in Figure 7 depends on the speed of data transmission through sensors. They record actual production records of renewable energy equipment and, for their purposes, can monitor the equipment's operating status in the event of a malfunction. Figure 7 shows that the data rate is of the order of 0.1 with data processing from 100 to 1,000 MB, indicating a good performance of information technology (IT) equipment in DCs. M2M devices serve as phase measurement units integrated into production and transmission equipment to continuously collect critical grid data such as voltage, current, harmonics, and frequency. Using excel, we calculated equation that describes correlation between time of data transmission and their capacity:

$$Time = 0.0006 \times Size + 0.0995;\ R^2 = 0.9657 \quad (1)$$

By incorporating RES and SDN-M2M technology, it is possible to calculate the average daily production capacity at service stations of RES plants over 12 hours, as shown in Figure 8. The average daily generation volume of WPPs is more efficient than solar panels and HPPs. The lowest power volume is 350-400 for HPPs for 3 hours due to low tidal activity. Solar panels have the lowest rate after 9 hours, where the volume decreases from 1,300 to 500 kWh, while the power output of WPPs falls from 1,500 to 850 kWh at the same time.

Data in Figure 8 allow concluding that the generation of energy from RES is insufficient for electricity supply in a large city. Furthermore, it is characterized by unforeseen circumstances during the operation of power plants, decreasing the overall efficiency. To increase energy efficiency and ensure electricity consumption by consumers, the complex energy produced during the day must be distributed.

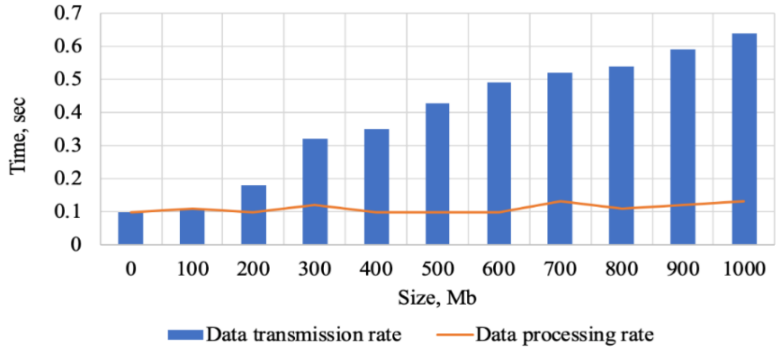

Figure 7. Dependencies of data transmission and processing rates from metering devices to DC

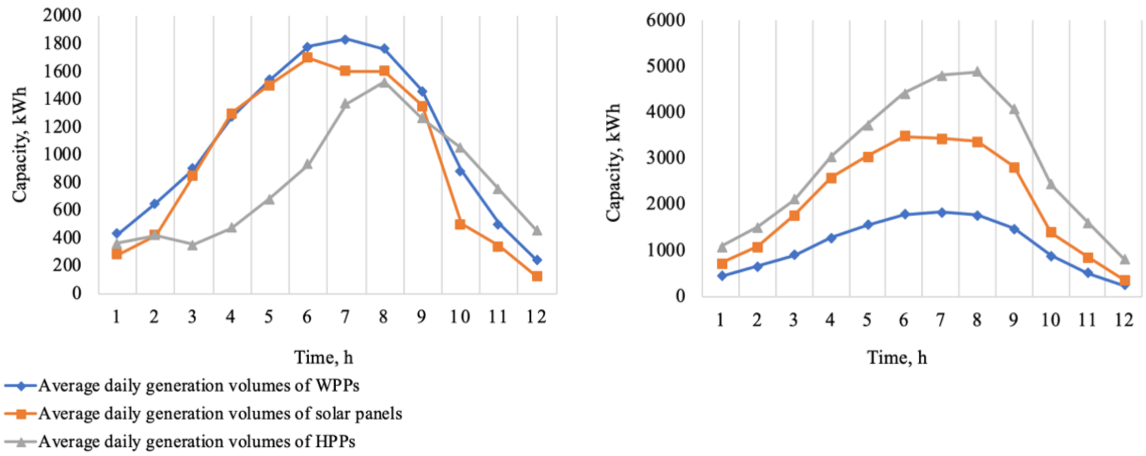

Figure 8. Average daily generation volumes of electricity from RES

This study considers the possible integration of RES into a software-defined M2M communication system and compares it with existing monitoring, control, and management techniques to identify the current shortcomings. M2M communication is one of the most active methods for managing power quality with sufficient equipment safety. It also enables the collection and processing of data at a distance, excluding human factors. At the same time, it is necessary to analyze the impact of information technology and the functioning of DCs operating using RES on the environmental situation.

Machine learning and artificial intelligence technologies are of equal importance. They may anticipate the potential to generate renewable energy through workload planning and implementation to improve alternative energy use energy efficiency. One such example is a scheduler called "GreenSlot" in Goiri *et al.* [20]. It is designed to forecast solar energy production as closely as possible, followed by DC workload planning to maximize the use of RES while meeting deadlines. This programming approach allows the DC to consume much more renewable energy by reducing the cost of conventional energy.

Uihlein and Magagna [21], statistical methods or physical models performed wave forecasting for tidal energy. Statistical approaches involve the application of neural networks and regression methods with genetic programming. They are represented, for example, by the wave forecasting systems based on physical models and the weighted average mark (WAM) wave model included in the integrated forecasting system (IFS) of the European centre for medium-range weather forecasts (ECMWF) [21], where forecasts can be a maximum of 48 hours ahead.

The integration of RES with DCs is now widely used in practice. Many IT companies have already built and transitioned to new DC that can operate partly or fully with renewables. One such company is Apple, which has created a 40 MW solar network for its data center in North Carolina to provide extra energy [22]–[28].

We summarized our results in 4 findings: i) we have determined that with an increase in the amount of data transferred, an increase in the duration of their transfer occurs. On average, an increase in the amount of data by 1 MB leads to an increase in processing time by 0.0006 seconds; ii) an increase in the amount of simultaneously processed data does not lead to an increase in the processing time; iii) we estimated the change in the amount of energy received from wind, solar and tidal energy. It has been established that wind energy can be used most efficiently within a 12-hour daily cycle, in contrast to tidal energy and solar energy; and iv) it is shown that due to the cyclical nature of obtaining energy from renewable sources, they do not fully provide energy to a large city.

4. CONCLUSION

This study analyzes the use of renewables in three ways with the possibility of combining alternative energy generation methods into a grid-connected system. By integrating RES with the software-defined communication technologies, a relationship was established between electricity generation and subsequent transmission of information to DCs. It allows monitoring the electricity generation volumes, which depend on the data transmission and processing rates from the sensor equipment to remote servers to display necessary distribution parameters for power supply to the end consumers. The study results showed that the data transmission speed has a delay of 0.6 seconds for processing information of 1,000 MB. Data processing rate depends on the speed of data transmission received from the equipment's sensors when the speed indicator does not exceed 2 seconds.

The study of three different power plants revealed that wind farms provide the most significant potential for generating electricity up to 1,600-1,700 kW. The need to combine plant complexes for more rational electricity use by consumers has been established. Each type of power plant has disadvantages, and thus, they are highly dependent on favorable conditions for the normal operation of the equipment. That is, solar panels require sunny weather, wind streams are critical for WPPs, tides and water flows specify the functioning of HPPs.

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